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ELECTRONIC DEVICES IN AIR TRANSPORT

By F. B. Lee

SURVEYING AND MAPPING, AIR TRANSPORT DIVISIONS

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PAPERS

ELECTRONIC DEVICES IN AIR TRANSPORT

By F. B. Lee[1]

Synopsis

Some of the aspects and implications of electronic devices used in air transport today, and those to be used in the immediate future, are treated in this paper. It is imperative for the groups interested in electronic navigation devices to exchange views with the groups interested in surveying, mapping, and charting, since navigation and charting are inseparably bound together. The development of the transportation and communications industries was made possible by the surveys, maps, and charts that preceded them. Conversely, those industries are placing increasing requirements on the mapping and charting industries to obtain more reliable charts and charts of extremely specialized natures.

An old map of the United States entitled "Standard Air Trail Maps" (presumably published in the late 1920's or the early 1930's) was essentially a record of the railroads, with major cities and towns served by them. Very meager terrain information was shown, and no radio information of any nature was indicated. The only navigation information, except for the old "iron compass" of the railroads, was the lines of magnetic variation. The reverse side of the chart contained matter explaining the use of the chart and information relating to air navigation. One statement on this old chart contained a lasting truth:

> "One of the important navigational instruments is an accurate air map; in fact, some of the other instruments of navigation are of value only as related to the map."

Concepts of navigation have changed greatly since the time of air trails maps which gave predominance to the railroads as a navigation device. Basic air navigation has progressed from the art of observing and recognizing objects on the ground with the unaided human eye to the art of observing position by

Note.—Written comments are invited for publication; the last discussion should be submitted by August 1, 1953.

[1] Deputy Administrator for Operations, Civ. Aeronautics Administration, Washington, D. C.

reference to instruments in the cockpit. This change of emphasis has been caused by the development of electronic devices for air navigation. This development has only begun and future developments cannot be foreseen. Therefore, the writer will discuss only those devices which are either available and in service or which are planned to be placed into service in the very near future.

The electronic devices used in the operation of aircraft, both in the cockpit and on the ground, by the government—by scheduled and other civil aircraft operators—are of such great quantity and variety that mere designation and description would consume considerable time. The devices used in air navigation are relatively few but are of tremendous importance to the welfare and security of the United States. The U. S. Armed Forces depend heavily on air transportation for the prompt and efficient movement of men and material. Schedule reliability is important to both the military and the civilian activities. In case of war, the ability to move bombers, fighters, and military transport aircraft in large numbers, regardless of weather, would be critical to the national defense. An air navigation system which will bring with it a higher degree of scheduled air carrier dependability and reliability would be extremely beneficial to the economy of the United States and could be measured in substantially increased passenger and cargo business. Manufacturers of private aircraft will reap benefits from any air navigation devices that will increase the use of small aircraft for business and pleasure.

The Civil Aeronautics Administration (CAA) is engaged in providing the ground facilities to be used in an air navigation system that has the attributes of the system just described. It was developed by the aviation industry itself including civil and military govermental, commercial, and private aviation interests. The name "common system" was chosen because there must be one system of air navigation and traffic control to be used in common by all aviation—civil and military—in the United States.

The "common system" was formally conceived in 1947 when the Radio Technical Commission for Aeronautics established Special Committee No. 31 to undertake a study for the purpose of developing recommendations for the control of expanding air traffic. That committee was composed of government agencies, aviation trade associations, radio manufacturers, airline pilot organizations, and others interested in, and connected with, aviation.

The committee reviewed and recognized the individual problems peculiar to specialized aviation operations, such as those of the scheduled airlines, military air transport, and other nontactical services, as well as the problem of commercial and private aircraft operators. The needs and requirements of all groups were studied, and a report was produced, accepted by government and industry, and adopted as a guide in the implementation and further development of the "common system" for the common good. Shortly thereafter, the Air Navigation Development Board (composed of representatives of the departments of Commerce and Defense who are specifically represented by the CAA, the Air Force, and the Army and Navy, with a chairman from industry) was created to guide and supervise the development of the electronic devices needed to implement the report of Special Committee No. 31 (RTCA-SC-31). In addition, the Air Coordinating Committee established an Air Navigation and

Traffic Control Panel (ANTCP) and charged it with the responsibility for developing the operational requirements for aids to air navigation and traffic control. This panel consists of government agencies (military and civil) representatives of the aviation industry, and private citizens responsible for the implementation of the "common system" or concerned with the use of the federal airways. Thus, the users of the air space have an active voice in molding the future character of the airways system.

The operational requirements developed by the ANTCP are forwarded to the Air Navigation Development Board which, guided by the requirements, formulates a unified program for research on, and development of, aids for the "common system." After an aid has been developed by the board, the specifications for the aid are presented to the implementing agencies. Under this system, the CAA has the responsibility to plan, install, and operate the ground aids required for the "common system" and to advise the users of the air space regarding airborne equipment.

In January, 1950, the ANTCP established an operational policy group to review the RTCA-SC-31 report and all other papers dealing with the "common system." This group was authorized to review and evaluate all information and materials pertaining to present and anticipated operational policies and procedures; it formulates programs for equipment development and makes reports and recommendations accordingly; and it was charged with taking into account the needs of the national defense and special problems of the users of the air space. The group was composed of representatives of the government, air transport and airline pilot organizations, airport operators representatives, and others. Its report[2] deals with the immediate future and contains the latest industry-wide thinking with respect to the "common system." The major electronic devices specified in the report which are related to air navigation and charting are especially timely.

The special working group report deals primarily with the "transition program," or a program that will raise aviation from its World War II status to the "common system" plane. Basically, the transition program (1) converts the navigation system to a new system which provides the pilot with continuous information as to his position in space; (2) utilizes radar as a traffic-control facility in congested terminal areas; (3) provides direct communications between the pilot and the air route traffic controllers; and (4) utilizes electronic and electro-mechanical techniques for the display and relaying of information.

The basic facility in the transition air navigation system is the very-high-frequency omni-directional radio range which will replace the low and medium frequency four-course radio ranges that have been in use since the 1930's.

The omni-range, as its name implies, provides an infinite number of tracks radiating from the transmitting site. For convenience, each omni-range is considered to have 360 tracks (of 1° width) which are designated as "radials" in magnetic degrees from the station. The omni-range operates in a very-high-frequency spectrum between 112 and 118 megacycles. The radio

[2] "Air Traffic Control and the National Security;" Report of the operational Policy Group of the Air Traffic Control and Navigation Panel, December, 1950; U. S. Govt. Printing Office, Washington, D. C.

characteristics of that frequency band are such that the omni-range is virtually static free but, at the same time, its propagation is limited to radio line-of-sight which is only slightly greater than optical line-of-sight. In general, the omni-range may be received at a distance of 30 miles at 500 ft above the ground station, 45 miles at 1,000 ft, with this reception distance increasing to 200 miles at 20,000 ft.

Inasmuch as the normal minimum altitude of aircraft operating on instruments is 1,000 ft above the terrain in nonmountainous areas and 2,000 ft above the terrain in mountainous areas, an area coverage of 45-mile radius is normally expected at minimum instrument altitudes.

The omni-range imposes some requirements on the airborne receiving system that were not present under the old low-frequency system in that the function of interpretation is transferred from the pilot to the electronic equipment in the new "common system." Under the old system, the airborne receiver picked up the ground signal, and the pilot detected courses and quadrants through discrimination of the relative signal strength of the Morse code characters *A* and *N*. The omni-directional receiver itself detects and interprets the course signals produced by the ground equipment and displays them visually to the pilot. The pilot is thus relieved of the monotonous task of listening continually to air navigation signal information and now merely needs to glance at an indicator to learn whether he is flying to or from the range station and whether his magnetic bearing is to or from the station.

Distance-measuring equipment (DME) has been developed to furnish additional safety and convenience, inasmuch as this equipment continuously informs the pilot of distance from the ground station. The distance-measuring equipment utilizes radar pulse techniques to measure the time interval for radar pulse travel from the aircraft to the ground equipment and return to the aircraft. Since the radar pulses travel at the uniform velocity of light, or 186,000 miles per sec, it is a relatively simple matter for the distance-measuring equipment to convert the time intervals into distances and display those distances in the cockpit on a meter graduated in miles. Thus, a pilot with equipment will know, continually and accurately, his distance and direction from the ground equipments located at fixed geographical points and, therefore, can determine his position in space accurately.

The development of an additional piece of electronic gear, the course line computer, has been coordinated with the development of the omni-range and distances-measuring equipment. This computer—an airborne electronic device—makes it unnecessary to fly directly to or from an omni-range because, with it, a pilot can fly a straight course between any two selected points covered by omni-range and DME signals. The computer using intelligence received from the omni-range and DME continuously solves the specific trigonometric problems involved in presenting information with respect to preselected courses and relieves the pilot of the burden of piloting and solving these navigational problems.

A further refinement of an electronic device to use information transmitted by omni-range and DME is the pictorial computer. Various pictorial computers are being developed, but essentially all of them receive

azimuth information from an omni-range and distance information from DME, and portray this intelligence on a chart as a moving marker which corresponds accurately to the position of the aircraft over the surface of the earth. These computers vary in size and complexity from a small lap model, in which the pilot manually inserts paper charts and information desired and observes his progress by watching a simple "crab" crawling over the chart, to more complex devices which may be mounted in instrument panels and which will project the proper chart and position of his aircraft thereon merely by turning in the appropriate ground station. Research studies conducted by the CAA indicate that navigation can be conducted by using pictorial display with an ease and simplicity never before thought possible.

The omni-range and DME, with their various airborne receiving and interpreting devices, are basically provided for en route or point-to-point navigation and are generally not considered to be suitable as precision approach aids. However, recent experiments and tests by the CAA have indicated that, although the omni-range may not be regarded as a precision approach aid, it offers more accuracy, reliability under atmospheric static conditions, ease of operation, and orientation than any low-frequency or medium-frequency aid currently used for making instrument approaches. Thus, the omni-range can serve two functions—(*a*) as a means of providing en route guidance and (*b*) as an adequate instrument approach device at those locations where density of traffic does not justify a precision approach aid.

The "common system" has within it two electronic devices for making precision instrument approaches during adverse weather conditions—the instrument landing system and precision approach radar. The two may be used separately, but the best results are obtained when both are considered and used as complementary facilities.

The instrument landing system (ILS) uses ground transmitters located at the airport to project two radial beams into space. One beam, called the "localizer," is directed down the runway into the approach zone. It provides lateral guidance to aircraft approaching the airport, keeping them on an electronic track over the runway center line, extended. The second beam, called the "glide path," controls the plane's rate of descent and angle of approach in the vertical plane. The pilot making an ILS approach watches a cross-pointer indicator in the cockpit and controls his course of flight by reference to these indicators. The use of the instrument landing system requires that the aircraft be equipped with a specialized receiver which will intercept and interpret the localizer and glide path signals and display them in convenient visual form to the pilot.

The precision approach radar is simpler to operate in so far as the pilot is concerned because no specialized receiver is required and the pilot merely follows the instructions issued to him from the ground controller in making an approach to the runway. The ground controller watches the aircraft on two radar scopes, one of which gives him the distance and the azimuth of the aircraft with respect to the touchdown point on the runway, and the other provides him with information on height or angle of elevation. Thus the controller follows the movement of the aircraft in the approach zone and directs

the pilot down to the runway by transmitting instructions over the radio telephone. Precision approach radar provides a means whereby a partly equipped aircraft may make an approach to an airport in a congested terminal area.

The CAA supplies both an instrument landing system and precision approach radar at the dense traffic airports which constitute the safest and surest landing method known. In general, aircraft equipped with ILS facilities employ those facilities in making the approach, and the CAA personnel monitor guides the aircraft on its approach with precision approach radar. Thus, two functionally different and independent electronic instrument landing devices are used as a double check to provide the highest possible safety for the users of federal airways.

The CAA is providing additional radar facilities to act as the eyes of the airport traffic controllers during periods of restricted visibility. These facilities are designated as airport surveillance radar (or ASR), and they show the controller, on a plan-position indicator, the location of all aircraft within 30 miles of the terminal. The ASR serves several general purposes in addition to the obvious one of reducing collision hazards. It is used to guide aircraft to positions where the precision approach radar can pick them up and pilot them down to safe landings, or to "vector" departing aircraft direct to their en route airway, thus greatly reducing departure delays. The ASR is also used to "vector" or "monitor" aircraft proceeding through the terminal area when necessary because of congestion. This facility introduces another strong element of certainty by ground monitoring, by revealing the direction of aircraft operating in reduced visibility, and by providing flexibility of routes in the terminal area.

The identification of aircraft by radar is somewhat laborious and time consuming, unless additional aids are used. One of the ground aids available for, and suitable to, this purpose is (very-high-frequency) automatic direction finding equipment used in association with airport surveillance radar. This equipment provides the controller with a visual means of identifying aircraft in voice contact with the controller. When the pilot presses his microphone button, a radial line appears on the radar scope bisecting the "pip" on the radar representing his aircraft. An airborne radar safety beacon provides an immediate means of identifying a radar target and greatly increases the range and the usefulness of the radar. In addition to the transition program of the "common system" used by the pilots, the ground personnel require a large number of electronic devices to be used behind the scenes to handle a large volume of high-speed aircraft. Some of these devices include automatic air-traffic-control plotting displays, remote radar displays for long-range radar, mechanical interlock units to expedite the exchange of information relating to the status of air traffic at specific locations, automatic relay and display of aircraft movement messages, high-speed communication networks interconnecting the air traffic centers, and other similar devices. Some of these devices are now in partial or experimental use and others are only in the developmental stage. Added together, they promise safety, efficiency, and reliability in the air transport field which will insure the dominance of the United States in the aviation field and will further imbed air transportation as

an integral part of the economy and daily life in this country. The effect of this program is being reflected in the steadily increasing volume of instrument flying in the United States, the increasing efficiency of the air-traffic-control system, the increasing reliability of scheduled air carriers, and the sureness with which the military can perform their missions.

Some of the foregoing equipment is expensive and complicated, and it requires relatively large ground forces to operate and maintain. The CAA must weigh the needs of air traffic against the cost of providing facilities that will offer complete reliability, essentially, under all weather conditions at all airports. Literally, billions of dollars would be involved if the federal government undertook an ambitious program of providing all-weather operations at all airports. Hundreds of millions of dollars would be involved if the CAA contemplated a program of installing at each airport served by a scheduled air carrier the aids that would permit the degree of all-weather operation that is now technically feasible. Realizing that programs of such magnitude are economically impractical, the CAA has carefully analyzed the needs and requirements of air traffic, and it has developed a program that will benefit the most people—one that can be implemented within the bounds of economic justification.

Traditionally, the CAA has established air navigation facilities to meet the operational needs indicated by the total volume of air traffic existing at the time the facility was established. Other factors, such as prevailing weather conditions, the mixed operation of various classes of aircraft, the proximity of other airports, and the pecularities of the geographical location have been taken into account.

As air traffic continues to increase, the problem of planning for adequate air traffic control, communications, airports, and air navigation aids becomes increasingly complex. Implementation can no longer be planned to meet all operational requirements without giving increased emphasis to the economic questions involved. Implementation plans must meet those operational needs that reflect an optimum return in terms of service rendered within the bounds of the national economic structure. This is not a compromise between safety and economics, but a realistic endeavor to provide maximum safety and reliability within available means. Since safety must not, and cannot, be compromised, aeronautical activity in areas not having complete facilities must be limited to meet required safety standards.

The search for an answer to the question of the extent to which the CAA may reasonably and profitably provide the modern electronic devices called for under the "common system" has led to intensive studies of air commerce and civil aviation in general. The studies are providing a firm and solid foundation for building an electronic system that is economically sound, in addition to being technically superior to any other system in common use in the world today.

The findings of these studies are neither startling nor new. In their simplest form, they merely reveal that the distribution and concentration of population within the continental United States establish the pattern and control the apportionment of air transportation in, and between, the com-

munities. It is said that a community's population, size, and its economic character fix its volume of terminal air commerce. Furthermore, the flow of air transportation between pairs of communities varies directly with the size of their population product, and inversely with the distance between them when allowance is made for such secondary factors as differences in the air-surface-distance ratio, the minimum effective distance for present day aircraft, the economic character of each community in a pair, and the density of communities within a geographic area.

The population of a community is obviously a fundamental factor in determining its volume of air traffic, since air transportation is the movement of people and things from one place to another. However, the population is not the sole factor, inasmuch as places in the same size group do not generate equivalent volumes of air traffic. Variations in the air traffic of communities within the same size group are associated with differences in their economic character, or the manner in which the economic livelihood of the community is achieved.

The volume of air passengers or aircraft operations in a community is not due to chance but is fixed by the community's population and economic character in the same way as are retail sales, automobile registrations, and trade outlets. Studies of air commerce from 1940 through 1950 show a high degree of correlation through the years, and thus provide a basis for making reasonable forecasts of a community's air transportation volume and, hence, its requirements for aviation facilities.

The 1950 census reveals that there are 4,720 urban places in the United States with a population of 2,500 or more. Of these 4,720 urban places, only 320 of them had a population of 25,000 or more. These 320 places account for 93% of the urban population and 59.3% of the total population of the United States; they are the focal points for the nation's entire economic system.

The civil aviation pattern follows the concentration of population. Some of the significant findings in this area reveal that 93% of all passengers, 95% of the air mail, and 96% of the air cargo originated at the top 126 of the approximately 500 communities served by the scheduled air carriers. The 139 communities of less than 10,000 population generated less than 2% of the passengers, less than 1% of the mail, and less than 0.5% of the cargo; but, they required more than 7% of the air carriers take-off and landing operations to glean this small revenue. The conclusions are that air commerce is concentrated in the large metropolitan areas that and the small cities played relatively unimportant roles in the field of air transportation.

A study of the airline passenger pattern reveals that the volume of traffic between a pair of communities is controlled by factors affecting both the communities rather than by factors affecting only one of the communities. The definition of air transportation establishes the population of communities in a pair as one of the primary factors affecting passenger flow. The combined effect of the population could be stated as either the sum or the product of the population of the two communities. The population product has been selected as the correct measurement of the combined effect of the population of the two communities in a pair because it takes into account the relative size of

both places. Substantial airline passenger traffic occurs only between series of communities having large population products.

The location of the large standard metropolitan areas, particularly the ones with a population of one million or more, determines the basic airline passenger pattern in the United States. The pattern can be likened to a series of wheels, the hubs of which are communities like New York, N. Y., Chicago, Ill., Los Angeles, Calif., Washington, D. C., and San Francisco, Calif., which are connected by "wheel spokes" to lesser "hubs" and "rim" points. High-density traffic moves between hubs, and there is a significant volume that occurs between a hub and a rim point. The volume of passengers for pairs in small cities is relatively unimportant.

In general, civil aviation follows essentially the same pattern of concentration in the large communities as do scheduled air carrier operations. One of the best indicators of general aviation activity is the civil aircraft population in a community. A study of the civil aircraft population indicates that the average number of civil aircraft registered in the large metropolitan areas is three hundred and this average dwindles to forty for the independent cities. Of the 3,000 locations with one or more civil aircraft as of January 1, 1950, nearly one half of them had less than ten aircraft and only fifty eight had more than two hundred.

The number of civil itinerant operations was measured and it was found that the large metropolitan districts averaged 22,500 operations annually, as compared with 7,500 operations with the independent cities.

A study of instrument approaches executed in 1950 indicated that the large metropolitan districts averaged 1,850 approaches annually, 1,500 of which were air carrier, 150 civil, and 200 military, whereas the smaller independent cities averaged 420 approaches, 350 of which were air carrier.

This knowledge about the economic demand for air transportation by the community has been related to the requirements for the "common system" electronic aids. The CAA has examined the benefits to be produced by each of these aids and has established criteria that specify whether or not a given community has sufficient civil aviation activities to qualify for the particular aids.

A specific example is the criteria for the establishment of a CAA airport traffic control tower. The more important ones included:

(1) The number of domestic enplaned passengers,
(2) The tons of domestic air mail dispatched,
(3) The tons of domestic enplaned air cargo,
(4) The number of domestic air carrier departures,
(5) The number of civil aircraft,
(6) The number of civil and military operations, and
(7) The number of itinerant operations.

Any one could have been selected as they have substantially the same community pattern. Air carrier operations were selected because they are most directly related to the primary function of a CAA airport traffic control tower—that is, the traffic control of interstate aircraft operations.

It would be desirable to have a tower at every airport if cost were not a factor. In order to provide maximum benefits with minimum costs, it was determined that airport traffic control service would be justified at airports having 7,000 or more annual scheduled operations, or at airports generating 4,000 scheduled operations annually if other classes of traffic are high enough in volume to qualify on the basis of a traffic count formula. Other exceptions may be made where peculiar or exceptional circumstances warrant.

Criteria for all other aids have been developed on a similar basis. The number of aircraft operations, or traffic density, governs the degree and type of service the CAA will provide at each location. Criteria, programs, and civil aviation requirements are reviewed continuously in order to provide the flying public with maximum benefits of the new electronic miracles at a price that can be afforded by the national economy.